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Look before planting: using smokewater as an inventory tool to predict the soil seedbank and inform ecological management and restoration.

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Summary

This study tested the efficacy of smokewater to determine the potential germination from soil seedbank in three management sites of the same National Park: a forest site prior to restoration, an ex-pine plantation site and an ex-mine site. This will provide further information to land managers so that more accurate planning can occur. Results showed that smokewater significantly increased the germination from the soil seedbank and significant differences in the level of germination of weed species from the soil seedbank were seen between the three management sites. This use of smokewater may be a useful tool to help predict differences in the soil seedbank compared with predicting soil seedbank based on land use history and recent condition.

Introduction

Successful land management requires accurate and reliable information on the characteristics of many plant species (Thomson, *et al.* 1993). Land managers are often faced with a high degree of uncertainty regarding the level of potential species establishment, particularly regarding weed species in the existing soil seedbank. This can make strategic planning difficult. However, it is sometimes possible to predict the response of vegetation to management activities from knowledge of the composition of the soil seedbank (Marks and Mohler 1985). If the soil seed bank could be analysed, it may be used as a predictive tool for land managers. However, collection of original seedbank data is often prohibitively labour intensive and expensive (Thomson, *et al.* 1993). This paper explores a glasshouse-based method that uses smokewater to help predict the potential weed soil seedbank and provide more information to land managers.

Karrikinolide, a butenolide found in smoke (Flematti, *et al.* 2004), has been used in the form of aqueous smoke (smokewater) or aerosol smoke to enhance seed germination in the South African fynbos (De Lange and Boucher 1990), Western Australian bushland (Dixon, *et al.* 1995), post-mining situations (Roche, *et al.* 1997); un-mined woodland (Rokich, *et al.* 2002) and in old-fields (Standish, *et al.* 2007). Collectively, these results show firstly, the wide range of uses of smoke and secondly, that the use of smoke has practical application by providing more information about the soil seedbank. Smokewater may be a useful and comparatively inexpensive tool to conduct an inventory the soil seedbank prior to making management decisions.

In this paper we aim to test the use of smokewater as an inventory tool at different management sites within a degraded *Eucalyptus gomphocephala* (Tuart) forest, the Ludlow Tuart Forest, in the south west of Western Australia. We focus on three management sites: a forest site pre-restoration, ex-pine plantation and ex-mine sites in which we aim to answer the following question: Can smokewater assist in predicting the weed soil seedbank of three different management sites within the same degraded forest and hence inform ecological management and restoration?

Methods

The Ludlow Tuart Forest (2049ha) is located 200 km south of Perth, Western Australia (33°35'08.72"S 115°29'30.57"E). The average annual rainfall is 811.9 mm, 80% of which falls between May and September (BOM 2009a). The nearest weather station is located in Busselton Shire, 15 km south-west of the site. The soils are classified as part of the Spearwood Dune System, consisting of variable depths of siliceous brown and yellow leached sands.

The three management areas in the Ludlow Tuart Forest are within 1 km of one another. The forest site prior to restoration is typical of degraded sites in the area, but has had some weed control over the past five years. It contains the dominant canopy species Tuart and low understorey diversity. The ex-mine site was in poor condition prior to mining and had the soil profile reestablished with original topsoil following mining (stored for 1-5 years) and was recently ripped. The ex-pine plantation site had been harvested for pine in the early 2000's (after >30 years under *Pinus radiata*) and was fallow. It was noted in the previous wet season that the forest site and ex-pine sites seemed to have much higher weed loads than the ex-mine site. Each of the three management areas was paired with a site in the adjacent Tuart forest – referred to here as 'off-site' sites . These, ideally, would have been reference sites however; there are no nearby sites that have a low level of disturbance. Therefore, sites were typical of the rest of the forest, which is degraded with a long history of grazing, logging and weed invasion. Major weed species were: Annual Veldt Grass (*Ehrharta longifolia*) Dune Onion Weed (*Trachyandra divaricata*) and Arum Lily (*Zantedeschia aethiopica*) (DEC 2007). Thus, there were six plots in total: 1) the ex-mine and 2) the adjacent Tuart forest; 3) the State Forest and 4) the adjacent Tuart forest; and 5) the ex-pine plantation and 6) the adjacent Tuart forest.

Soil samples were taken in May 2007 just prior to the start of the winter rains to allow temperature-sensitive seeds to be responsive. At 25 sampling points located randomly within each of six plots, five sub-samples of 10 cm x 10 cm to 2 cm depth were collected at each sampling point, bulked and placed in calico bags. The majority of the soil seed bank is held within the top 2.5 cm of the surface (Bellairs and Bell 1993).

The 150 (25 samples at 6 plots) soil samples were air-dried; each mixed thoroughly then split into two sub-samples. Sub-samples were spread to a depth of 2 cm over a layer of steam-sterilized sand in lined but free-draining plastic trays, which measured 11 cm (width) x 16.5 cm (length) x 5 cm (depth). A liquid soil wetting agent (Brunnings Easy Wetta ™) was applied to all trays to reduce hydrophobicity. Half of the trays were treated with diluted (10%v/v) smokewater at the equivalent of $50ml/m^2$. Smokewater was created by bubbling smoke from a drum of burning hay through a 20 L container of water for 1 hour (Dixon, *et al.* 1995). The seedling trays were arranged in an evaporative cooled glasshouse (Mean Max. 28.5 ^{o}C Mean Min. 19.2 ^{o}C) in May 2007 and watered regularly. Trays were randomized fortnightly. Germinants were counted as they appeared after 3 and 10 months (data presented is that from the latter).

Statistical analysis

Data were analysed as a repeated measures ANOVA for each site separately. There were two repeated measures variables for each site: smoke water (present or absent) and location (on-site, offsite – i.e. different management sites and adjacent forest sites). There were only two levels of the repeated measures factors, so there was no need to incorporate corrections for possible violations of the sphericity assumption (von Ende 2001).

Results

Germination density rates were significantly higher in the smokewater treated plots relative to those not treated at all sites, and also higher in the ‘off-site’ sites. There was a difference in germination density between the three management areas, with the mine-site having the lowest germination, followed by the forest site, and the ex-pine site having the highest germination. At the Tuart forest site the interaction between smokewater treatment and ‘on-site’ and ‘off-site’ plots was also significant, with the effect of smokewater more strongly marked off-site (Table 1, Figure 1).

Weed species dominated in the seedling trays at all sites, particularly Annual Veldt Grass (recorded in 54 % of trays and from all sites). Other weeds noted were Dune Onion Weed (7 %), which occurred in all sites and Arum Lily (2 %) only in the ‘off-forest’ trays. The only recorded native species emerging was the mid-canopy dominant, Peppermint (*Agonis flexuosa*) (5 %) and it was recorded in all trays except for ex-pine and ex-mine sites.

Implications for management

The use of plant-derived smoke has been utilized as a means of determining the potential soil seed bank in old-fields (Standish, *et al.* 2007), and forest communities (Read, *et al.* 2000). However, the current study is the first to analyse different management areas within one forest with the aim of informing land managers. The differences in germination rates (the majority of which were weeds) between the three management areas could be a reflection of their previous land use. For example, the ex-mine site had a lower weed load than the other sites, perhaps because of topsoil storage and mixing during the ripping process. The fact that very little native germination and a high weed load were detected at all sites is probably due to the high level of disturbance at all sites in this forest. Nonetheless, the results depict the potential abundance of weeds and some of the species that may challenge land managers.

There are clearly limitations to this type of study. Firstly, it only tested seed germination response to a particular smoke concentration; different concentrations or smoke in addition to heat should be studied. Secondly, restoration strategies should not only be based on this aspect of the soil seedbank but take into account other factors, including prior land use and management. However, this use of smokewater can provide land managers with a somewhat greater level of understanding of the composition of the soil seedbank rather than based on land use history and recent condition.

Given this new information, land managers could make more informed decisions about prioritization of management options, including project type, site selection, timeline of activities and cost-effectiveness. They may wish to include such information in a decision support system. For example, managers may wish to postpone treatment until financial resources can match the amount of weed management input required, or budget and plan for a particular suite of weed control methods, depending on the invasive species found in the soil seedbank. Furthermore, managers may wish to select a particular native species mix and planting/seeding density as part of revegetation activities to ensure that species with particular functional traits are chosen that provide a high competitive ability in the face of particular invasive species composition and abundance.

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Table 1. Results of repeated measures ANOVA for each site (forest, minesite, and pine), with smoke water (present or absent) and location (on-site and off-site) as the repeated measures variables.

		Forest		Minesite		Pine	
Effect	df (effect, error)	F	p-level	F	p-level	F	p-level
Location (on- or off-site)	1, 24	21.335	> 0.001	20.447	> 0.001	0.362	0.553
Smoke water treatment (present or absent)	1, 24	35.541	> 0.001	10.784	0.003	6.736	0.016
Location, Smoke water treatment	1, 24	7.339	0.012	3.766	0.064	0.035	0.854

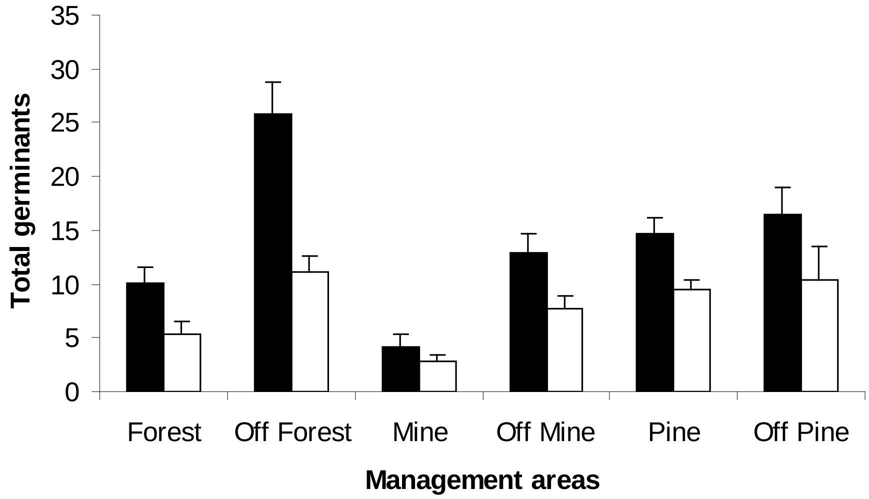

Figure 1. Mean number of germinants per plot for three management areas and paired sites ("Off"-) in the Ludlow Tuart Forest, with (black bars) and without (white bars) the addition of smoke water. Values are means (± SE) of 25 samples.